MODEL PREDICTIVE TORQUE CONTROL OF INDUCTION MOTOR USING SVPWM

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ABSTRACT

Induction motor and its controlling techniques proposed by various researchers, but each technique contain some of common problem such as high torque ripple and variable switching frequency at low-speed region. Breakthrough in this controlling research adopted while using Conventional MPTC method, which suffers from complexity and time compensation problems. This paper proposes a Model Predictive Torque Control (MPTC), which eliminates the control complexity, by using SVPWM as cost function minimization technique. This new method eliminates the requirement of time delay compensation, which simplified the prediction model in Model Prediction Control Algorithm. Experimental result show that improved switching instant effectively reduces the torque and flux ripple in proposed MPTC.

Keywords—Induction Motor (IM), Model Predictive Torque Control (MPTC), Space Vector Pulse Width Modulation (SVPWM).

INTRODUCTION

Since induction motor was invented, it becomes the generally used motor in industry. Unfortunately, induction motor requires more expensive equipment for speed control, due it's inherently a dynamic, recurrent, and nonlinear system than DC motor. Then came Direct Torque Control (DTC), Developed by Takahashi, it provides better dynamic control of torque (Komorowska, M.P. and Buja, G., 2003). After some studies on DTC for IM, one of disadvantage is tuning of weightage (Casadeiet al., 2002; Brando et al., 2015). Some methods have been introduced in literature to mitigate these problems such as fuzzy- neuro logic control (Ponce et al., 2014), MRAS (Sayouti et al., 2009). Some study revels, Predictive Current Control (PCC) give higher ripple than Prediction Torque Control (PTC) (Beerten et al., 2009; Miranda et al., 2009).

Also observe that PTC (Lascu et al., 2016) give error during control due to magnetizing inductance of Induction machine, while PCC degrade its performance by having stator resistor detuning. MPTC based on online optimization for controlling parameter replacing conventional table-based DTC having investigative switching table (Casadei et al., 2002). Best voltage vectors were selected to minimize cost function, which it relates to torque and flux error. Resulting accurate and effective vector for minimizing the cost function than conventional DTC (Kazmierkowski, M.P. and Buja, G., 2003).

The fact is assured when conventional table-based DTC is compared with MPTC (Rubino et al., 2018). Usually single voltage vector is selected and hold until next period of controlling mechanism update, in conventional MPTC. Some also show that single Vector can helpful for achievable performance using MPTC (Zhang, Y., Xia, B., Yang, H. and Rodriguez, J., 2016.). Steady state performance is major issue while controlling IM, this can be ease by the concept of duty cycle control. This MPTC Method use control period in two parts: first part uses nonzero selected vector and other use an appropriate zero vectors. This method increases the switching frequency by applying two voltage vectors at different instant of control period (Song et al., 2017; Zhang, Y.

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and Yang, H., 2014; Zhang, Y. and Yang, H., 2015). Recently, some paper shows optimized switching control using two steps forward controls (Zhang, Y., Yang, H. and Xia, B., 2016). Using MPTC for IM, using a two-step predictive algorithm provides time compensation. Also, use of two or three vector in a control period will improve the overall performance of MPTC in industrial application. This paper proposes a new model of predictive torque control strategy using the space vector PWM (Van Der Broeck et al.,1988), using the space vector as a cost function minimization tool. Space vectors reduce the changing state naturally and optimize the model estimate to significantly reduce torque and flux waves. The components follow the applicable standards.

DYNAMIC MODEL OF IM

The mathematical model of IM is then used in the stator-fixed reference frame (α, β) employed in the subsequent consideration is given by (Aamiovuori et al., 2018):

$$\dot{x} = Ax + Bu \qquad \text{……………………(1)}$$

Where x= $(i_s \Psi_s)^T$ represent the value of state variable,and u=u_s is a necessary part of control called stator voltage vector, and

$$A = \begin{bmatrix} -\lambda(R_s L_r + R_r L_s) + jw_r & \lambda(R_r - jL_r w_r) \\ -R_s & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \lambda L_r \\ 1 \end{bmatrix}$$

$$\lambda = 1/(L_s L_r - L_m^2)$$

Where R_s,R_r,L_s, Lr are representation of stator and rotor resistance and inductance, L_m represent mutual inductance, respectively, w_r is the speed at which rotor of Machine run in electrical degree

In next control instant using (1), values of stator current and flux can be discretize using most popular first-order Euler method. However, this method has relatively low accuracy than Cayley-Hamilton theorem, which requires high computation for calculation of matrix exponential. In this paper, to obtain an accurate estimate of the stator current and stator flux, the second-order Euler discretion is chosen for discretion (1), even if the computational load is not greatly increased, expressed as:

$$\begin{cases} x_p^{k+1} = x^k + t_{sc}(Ax^k + Bu_s^k) \\ x^{k+1} = x_p^k + \frac{t_{sc}}{2} A\left(x_p^{k+1} - x^k\right), \end{cases} \qquad \text{..……………………(2)}$$

x_p^{k+1} is the state vector in (2), which predicted in control period t_{sc} and where at k+1 instant it predicted $x^{k+1} = [i_s^{k+1} \quad \psi_s^{k+1}]^T$

Rotor flux on k+1 instant can be estimated as

$$\psi_r^{k+1} = \frac{L_r}{L_m}\psi_s^{k+1} - \frac{1}{\lambda L_m} i_s^{k+1} \qquad \text{……………………(3)}$$

And the electromagnetic torque can be predicted as:

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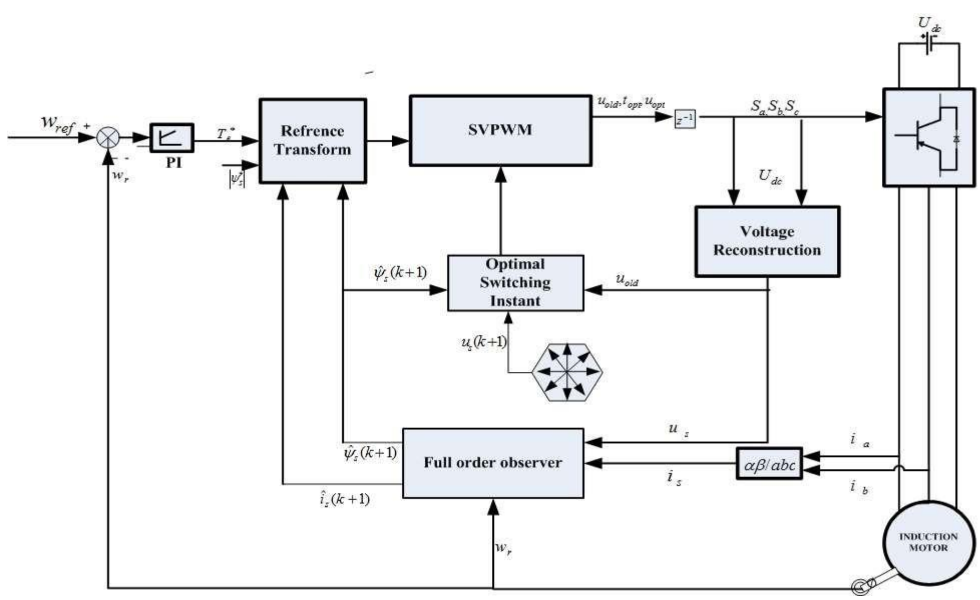
$$T_e^{k+1} = \frac{3}{2} N_p \psi_s^{k+1} \otimes i_s^{k+1} \quad \text{……………………(4)}$$

PROPOSED MPTC

We propose another model of predictive torque control as demonstrated in Figure.1. In the propose work to optimize cost function, we needed just a single voltage vector of two nearby vectors to diminish the switching transition, at that point the estimation of such a vector gets worthwhile at any second. It utilises the control activities for minimising the cost function into horizon using voltage vector of various greatness fittingly incorporated to create a sub cycle of steady time span. To achieve this undertaking, we define the control activities so that they duplicate, over an examining period Ts by utilizing SVPWM. Space vector diminish the cost function intrinsically and limit the switching instant utilizing examining period Ts. The model predictions utilizing this method upgrade the switching of MPTC (Yusivar, F. and Sembiring, R.J., 2013).

FIGURE 1:
SVPWM BASED PROPOSED IM CONTROL SYSTEM.



The cost function effectively reduces the average switching frequency in the proposed technology (Habibullah et al., 2016). The proposed strategy has an additional reduction in the MPTC calculation weight. Proposed MPTC use following for cost function expression using (3), (4):

$$\min J = k_\psi\left(|\psi_s^*| - \left|\psi_s^p(k+1)\right|\right) + k_T\left(|T_e^*(k+1)| - \left|T_e^p(k+1)\right|\right) \quad \text{……………………[5]}$$

In Conventional MPTC, hit and trial method is applied to find the appropriate weighting factor for cost function minimization. Time delay is required in above process using [5], to execute the process in more practical manner by calculating the prediction and estimate the state variable in two stages.

At some moment k+2, stator flux $\psi_s^p(k+1)$ and stator current use for calculation of estimated flux and torque for previous time period k+1.This ψ_s^p(k +1) and$i_s^p(k+1)$ are estimated by Then V_{opt}(k)

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is applied to IM is choose such that it estimate the ψ_s^p(k +1) and $i_s^p(k+1)$ state variable for k+1 instant. Subsequently, to carry out the delay compensation scheme, the optimum voltage vector is selected by minimizing the following cost function:

$$\min J = k_\psi\left(|\psi_s^*| - \left|\psi_s^p(k+2)\right|\right) + k_T\left(|T_e^*(k+2)| - \left|T_e^p(k+1)\right|\right) \quad \text{……………………..[6]}$$

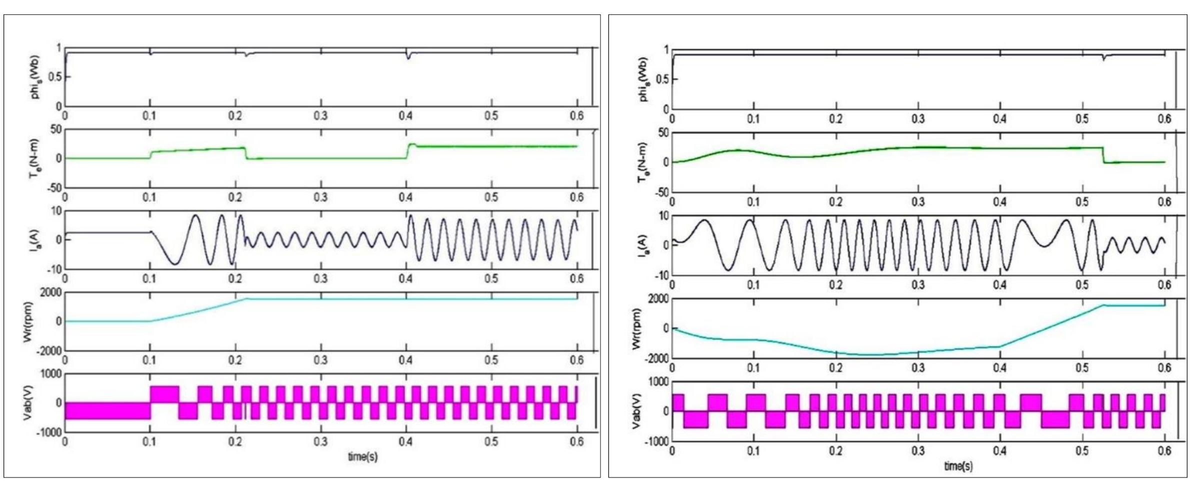
TABLE 1
MACHINE AND CONTROL PARAMETERS (SONG ET AL., 2017)

1.	**Rating of Induction Motor**	5.5kW; 6.8A; 380V; 50Hz; 40N-m; 1480rpm;2 Pole Pair
2.	**Induction Motor Stator and Rotor Winding Parameter**	R_S(Ω) :0.813 R_r(Ω):0.513Lm (mH):228L_S (mH):240L_r (mH):240
3.	**Control Parameter of Motor**	Sampling Frequency (kHz):6 Flux Amplitude Reference (Wb):0.91 kΨ:02 k_T:01

SIMULATION RESULT

Simulink result are proposed for new MPTC technique using MATLAB/Simulink software, for different loads and speeds. Prediction model evaluate the instantaneous state variable at k and predict the values at k+2 instant in Simulink model.

FIGURE 2
(A): SIMULATION RESULT FOR VARIATION LOAD FOR 0.1 TO 0.2SEC AT 30N-M AND OTHER IS FOR 0.4 TO 0.6SEC AT 40 N-M AT 1500 RPM; (B) SIMULATION RESULT FOR SUDDEN CHANGE IN LOAD FOR 0.35 TO 0.6 SEC AT 1500 RPM.



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Simulation parameter contain in Table. 1 used to evaluate the state variable in newly proposed MPTC method. Simulation is first proposed for variable load at two different time intervals, shown Figure 2(a) for 0.1 sec to 0.2 sec at 30 N-m and other is for 0.4 sec to 0.6 sec at 40 N-m. Detail variation are shown in Figure 2 (a), where top to bottom curve to be stator flux, Torque, stator current, speed, and phase voltage with respect to time respectively. Torque and flux error are reduced drastically as desire in proposed MPTC technique for wide speed range control.

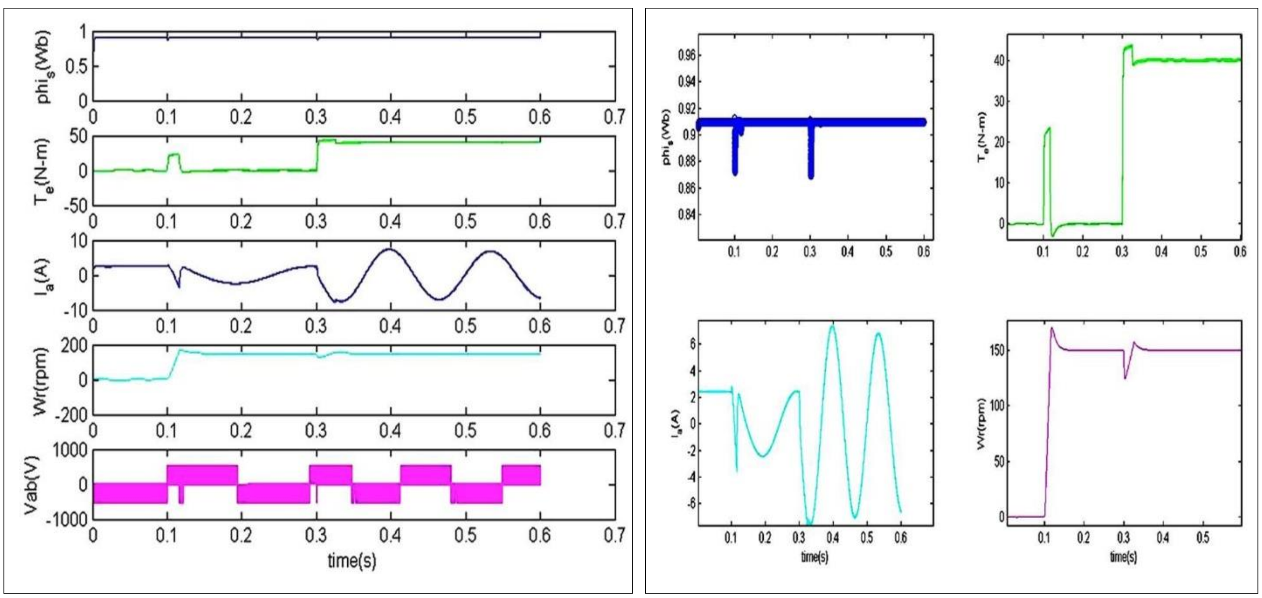
Figure 2(a) show the study of IM at 100% rated torque, under steady state condition analysis for flux and torque (Kirankumar, B., 2017). This Proposed method is more effective for optimization of switching instant using SVPWM in proposed MPTC than conventional MPTC.

Proposed MPTC result show in Figure 2(b) indicate low flux and torque ripple under sudden reduction torque load for time interval 0.35 sec to 0.6 sec at constant 1500 rpm. Details of flux and torque ripple in time interval 0.35 sec to 0.6 sec, verify that by effective switching vector we can reduce ripple in IM.

FIGURE 3:

(A): SIMULATION RESULT AT 150RPM (LOW SPEED)

(B)SIMULATION RESULT FOR INITIAL TIME INTERVAL AT 150RPM



Parameter variation at low-speed range depicted in Figure 3(a) shown, where proposed MPTC vary the machine parameter for adverse condition for knowing reliability of controlling technique. Proposed model approach to low harmonic distortion even at low-speed range and average switching frequency create load torque to almost constant. More advantages are also to be apparent, such as less torque and flux ripple.

Figure 3(b)show the Sinusoidal current waveform in Proposed MPTC, this waveform analyzed due to inherent property of IM to have large ripple at initial time. The wide speed of operation gives minimal change in ripples for any change in range of proposed MPTC method (Kirankumar, B., 2017). In proposed MPTC, low tracking error are observed due to use of Full order observer, give precise control to stator in low-speed range and has some strength against variations of machine parameters (Song et al., 2017).

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CONCLUSION

This paper present MPTC strategy for IM control, which allowed use of SVPWM to reduce the flux and torque error at low speed by minimizing the cost function. Simulated result show that, this method also used at different magnitude for swift operation of IM. This method also achieved the constant time duration for a sub cycle with minimum harmonic content. One of the major advantages to use this method is minimum computation time for standard MPTC, with incremental capability to precise control of IM. This provides an all-round performance in each region of IM controlling, by simple felicitation of SVPWM for producing voltage vectored in addition with MPTC method using heuristic table for each optimal switching instant. This paper gives further scope of research, having use of stator vector position in reducing computation time.

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